Week 16

AP Physics 2

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

AP Physics 2 Name: ____________ Score: ________

1. Two north poles are brought together. They:
   - ☐ attract
   - ☐ repel
   - ☐ do nothing
   - ☐ merge into one pole
2. A 2 C charge moves at 3 $\frac{\text{m}}{\text{s}}$ across a 4 T field (right angles). What force does it feel, in N?

   ____________ N
3. A 0.5 m wire carries 4 A across a 2 T field. What force does it feel, in N?

   ____________ N
4. A 100-turn coil has its flux change by 0.02 Wb in 0.5 s. What is the size of the induced EMF, in V?

   ____________ V
5. Outside a magnet, field lines point:
   - ☐ from south to north
   - ☐ from north to south
   - ☐ randomly
   - ☐ straight up
6. The magnetic force on a moving charge is directed:
   - ☐ along the velocity
   - ☐ along the field
   - ☐ perpendicular to both velocity and field
   - ☐ opposite the velocity
7. The force on a current-carrying wire in a magnetic field is:
   - ☐ $F = qvB$
   - ☐ $F = BIL$
   - ☐ $F = IR$
   - ☐ $F = ma$ only
8. What is needed to induce a voltage in a co

☐ a steady magnetic field

☐ a changing magnetic flux

☐ a stationary magnet inside it

☐ a large resistance

9. You can cut a bar magnet to obtain a single, isolated north pole.

   ☐ True ☐ False

10. A stationary charge in a magnetic field feels no magnetic force.

   ☐ True ☐ False

AP Physics 2

1. **repel**

   Like poles repel, just as like charges do.

2. **24 N**

   $F = qvB = 2 \times 3 \times 4 = 24$ N.

3. **4 N**

   $F = BIL = 2 \times 4 \times 0.5 = 4$ N.

4. **4 V**

   $|\varepsilon| = N\Delta\Phi/\Delta t = 100 \times 0.02/0.5 = 4$ V.

5. **from north to south**

   Outside a magnet, field lines run from the north pole to the south pole.

6. **perpendicular to both velocity and field**

   The force is perpendicular to both the velocity and the field.

7. $F = BIL$

   $F = BIL$ — the motor-effect force on a current.

8. **a changing magnetic flux**

   Only a changing flux induces an EMF; a steady field does nothing.

9. **False**

   Poles always come in pairs; each piece of a cut magnet has both N and S.

10. **True**

    The magnetic force needs motion: $F = qvB$ is zero when $v = 0$.

AP PHYSICS 2 • EXERCISE SHEET

12.1 Magnetic Fields

Name: ____________ Class: ________ Date: __________ **Total: 8 marks**

KEY WORDS magnetic field 磁场

Objective

Build the skills to answer exam questions on **magnetic fields**.

You must be able to:

- describe a **magnetic field** 磁场 $\vec{B}$ as a vector field from magnets and moving charges
- draw magnetic field lines, noting they form **closed loops** with no isolated poles
- use a compass or the right-hand rule to find the field direction around a magnet

1 Worked examples

Study these first. Each one shows the method for a question type used later.

The magnetic field

$\vec{B}$ is a vector field, measured in tesla (T), produced by magnets and by moving charges (currents).

Field lines

Magnetic field lines form **closed loops**, leaving the north pole and entering the south. There are **no isolated poles** (no magnetic monopoles).

Finding the direction

A compass needle lines up with the field; the right-hand rule gives the field around a current.

2 Practice

2.1 State two things that can produce a magnetic field. [1]

2.2 State whether magnetic field lines are open or closed. [1]

2.3 State why isolated magnetic poles (monopoles) are never found. [1]

3 Exam-style questions

3.1 Magnetic field lines [1]

- **A** start and end on charges
- **B** form closed loops
- **C** are always straight
- **D** do not exist

3.2 A magnetic field can be produced by [1]

- **A** a stationary charge
- **B** a moving charge
- **C** a neutral atom at rest
- **D** none of these

3.3 A bar magnet is cut in half.

(a) State what each half becomes. [1]

(b) Explain your answer in terms of magnetic poles. [2]

Solutions

2.1 magnets and moving charges (currents).

2.2 closed (loops).

2.3 every magnet has both a north and a south pole; splitting it just makes two smaller magnets.

3.1 **B**.

3.2 **B**.

3.3 (a) each half becomes a complete magnet with its own north and south pole. (b) magnetic poles always come in pairs — there are no monopoles — so a new pair of poles appears at the cut.

Question 3

The following information applies to parts A and B.

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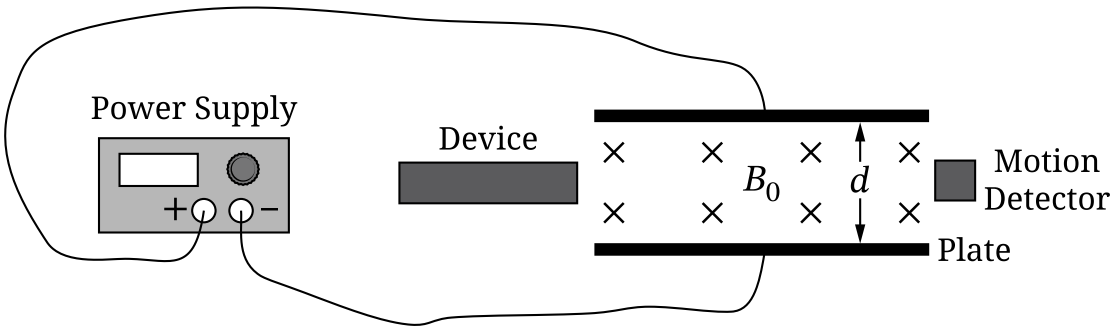
3. In Experiment 1, scientists want to collect data that can be graphed to determine the magnitude B_0 of an external, uniform magnetic field. The field is directed into Figure 1 in the region between identical, parallel, conducting plates that are connected to a power supply of variable emf ε. The plates are a known distance d apart, where d is much smaller than the dimensions of the plates.

Figure 1



Note: Figure not drawn to scale.

In each trial, a device emits small, charged spheres with speed v through the region between the plates. ε is varied until the spheres move undeflected toward a motion detector. The scientists can vary v between trials. Gravitational effects are negligible.

In addition to the equipment shown in Figure 1, the scientists also have access to a voltmeter. The scientists do not have access to other measuring tools, devices, sensors, or equipment.

Part A

i. **Indicate** quantities that could be measured using the available equipment that would allow the scientists to determine B_0 by using a linear graph.

ii. Briefly **describe** a method to reduce experimental uncertainty for the measured quantities indicated in part A (i).

Part B

i. **Indicate** what quantities the scientists could graph on the horizontal and vertical axes to create a linear graph that can be used to determine B_0. Clearly indicate which quantity corresponds to each axis.

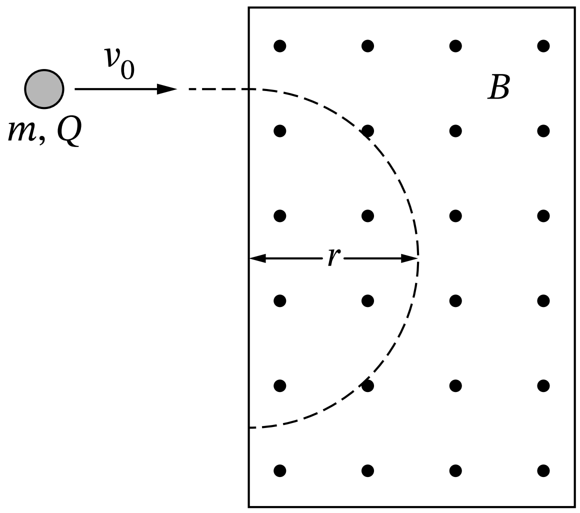
ii. Briefly **describe** the relationship between B_0 and one feature of the graph from part B (i). Your answer may include an equation that relates B_0 and the indicated feature of the graph.

The following information applies to parts C and D.

In Experiment 2, scientists want to use a graph to determine the mass m of identical, charged particles that are emitted from a device. Each particle has charge $Q = +6.4 \times 10^{-19}$ C.

In each trial, a particle is emitted with speed $v_0 = 3.0 \times 10^6$ m/s toward a region of external, uniform magnetic field of variable magnitude B. The radius r of the path along which the particle moves while in the field, shown in Figure 2, is recorded.

Figure 2



In subsequent trials, B is increased and the resulting r is recorded. Gravitational effects are negligible. Collected data are provided in Table 1.

Table 1

B (T)	r (m)
0.04	1.8
0.06	1.2
0.14	0.5
0.16	0.4
0.20	0.3

Part C

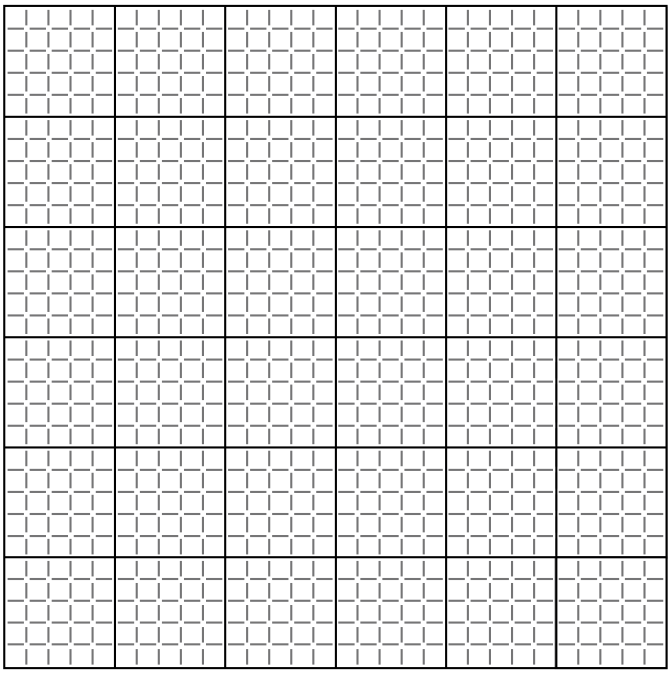
i. **Label** the axes of the grid provided with measured or calculated quantities. Include units, as appropriate. The graphed quantities should yield a linear graph that can be used to determine m.

ii. On the grid, create a graph of the quantities indicated in part C (i).

- **Label** the vertical and horizontal axes with numerical scales.
- **Plot** the corresponding data points on the grid.
- Table 2 is provided in your booklet for scratch work, but the table will not be scored.

Quantity (units, if appropriate)

__________ __________



Quantity (units, if appropriate)

__________ __________

iii. **Draw** a best-fit line for the data graphed in part C (ii).

Part D

Calculate *m* from the best-fit line drawn on the grid.

12.2 Magnetism and Moving Charges

Name: ______________ Class: __________ Date: ____________ **Total: 9 marks**

KEY WORDS magnetic force 磁力 • right-hand rule 右手定则 • magnetic field 磁场

Objective

Build the skills to answer exam questions on **magnetism and moving charges**.

You must be able to:

- calculate the **magnetic force 磁力** on a moving charge, $F = qvB\sin\theta$
- use the **right-hand rule 右手定则** to find the direction of the force
- describe the circular path of a charge moving perpendicular to a uniform field

1 Worked examples

Study these first. Each one shows the method for a question type used later.

Force on a moving charge

$F = qvB\sin\theta$, where θ is the angle between $\vec{v}$ and $\vec{B}$. The force is **maximum** when $v \perp B$ and **zero** when they are parallel.

Direction

The force is perpendicular to **both** $\vec{v}$ and $\vec{B}$ — use the right-hand rule (for a positive charge).

Circular motion

A charge moving perpendicular to a uniform field is pushed sideways continuously, so it travels in a **circle**.

2 Practice

2.1 A charge of 2.0×10^{-6} C moves at 3.0×10^{4} m s^{-1} perpendicular to a 0.20 T field. Find the force. [2]

2.2 State the angle between $\vec{v}$ and $\vec{B}$ that gives the maximum force. [1]

2.3 State the shape of the path of a charge moving perpendicular to a uniform magnetic field. [1]

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3 Exam-style questions

3.1 The magnetic force on a moving charge is [1]

- **A** qE
- **B** $qvB\sin\theta$
- **C** $BI\ell$
- **D** $\frac{1}{2}mv^2$

3.2 A charge moving parallel to a magnetic field feels a force of [1]

- **A** maximum size
- **B** zero
- **C** qvB
- **D** qE

3.3 A proton ($q = 1.6 \times 10^{-19}$ C) moves at 5.0×10^6 m s^{-1} perpendicular to a 0.30 T field.

(a) Find the magnetic force on it. [2]

(b) Describe the shape of its path. [1]

Solutions

2.1 $F = qvB = (2.0 \times 10^{-6})(3.0 \times 10^{4})(0.20) = 1.2 \times 10^{-2}$ N.

2.2 90° (perpendicular).

2.3 a circle.

3.1 **B**.

3.2 **B**.

3.3 (a) $F = qvB = (1.6 \times 10^{-19})(5.0 \times 10^{6})(0.30) = 2.4 \times 10^{-13}$ N. (b) a circular path.

Question 3

The following information applies to parts A and B.

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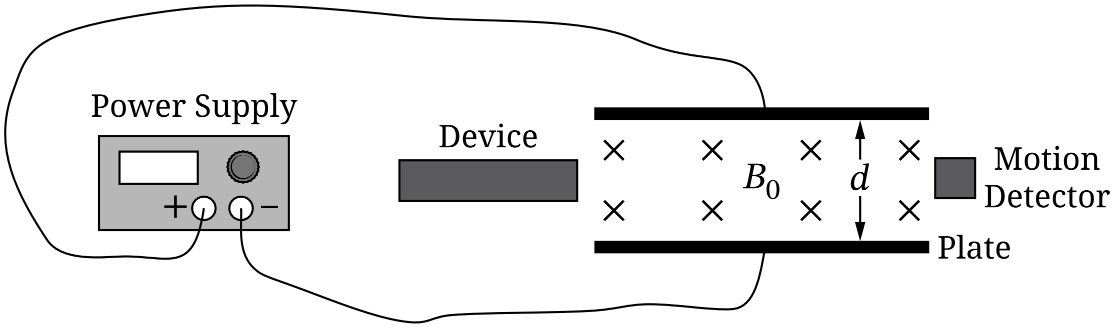
3. In Experiment 1, scientists want to collect data that can be graphed to determine the magnitude B_0 of an external, uniform magnetic field. The field is directed into Figure 1 in the region between identical, parallel, conducting plates that are connected to a power supply of variable emf ε. The plates are a known distance d apart, where d is much smaller than the dimensions of the plates.

Figure 1



Note: Figure not drawn to scale.

In each trial, a device emits small, charged spheres with speed v through the region between the plates. ε is varied until the spheres move undeflected toward a motion detector. The scientists can vary v between trials. Gravitational effects are negligible.

In addition to the equipment shown in Figure 1, the scientists also have access to a voltmeter. The scientists do not have access to other measuring tools, devices, sensors, or equipment.

Part A

i. **Indicate** quantities that could be measured using the available equipment that would allow the scientists to determine B_0 by using a linear graph.

ii. Briefly **describe** a method to reduce experimental uncertainty for the measured quantities indicated in part A (i).

Part B

i. **Indicate** what quantities the scientists could graph on the horizontal and vertical axes to create a linear graph that can be used to determine B_0. Clearly indicate which quantity corresponds to each axis.

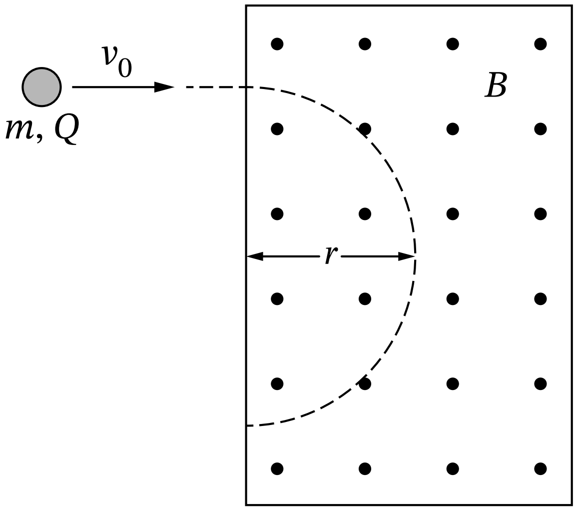
ii. Briefly **describe** the relationship between B_0 and one feature of the graph from part B (i). Your answer may include an equation that relates B_0 and the indicated feature of the graph.

The following information applies to parts C and D.

In Experiment 2, scientists want to use a graph to determine the mass m of identical, charged particles that are emitted from a device. Each particle has charge $Q = +6.4 \times 10^{-19}$ C.

In each trial, a particle is emitted with speed $v_0 = 3.0 \times 10^6$ m/s toward a region of external, uniform magnetic field of variable magnitude B. The radius r of the path along which the particle moves while in the field, shown in Figure 2, is recorded.

Figure 2



In subsequent trials, B is increased and the resulting r is recorded. Gravitational effects are negligible. Collected data are provided in Table 1.

Table 1

B (T)	r (m)
0.04	1.8
0.06	1.2
0.14	0.5
0.16	0.4
0.20	0.3

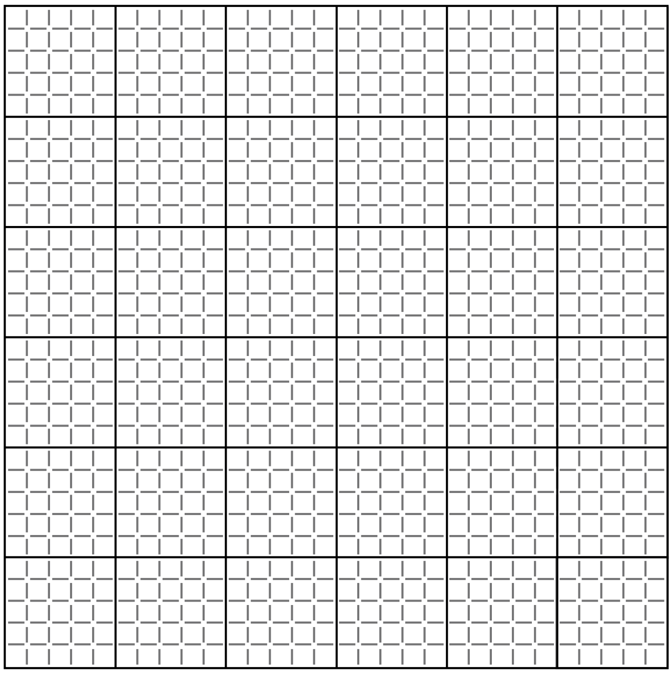
Part C

i. **Label** the axes of the grid provided with measured or calculated quantities. Include units, as appropriate. The graphed quantities should yield a linear graph that can be used to determine m.

ii. On the grid, create a graph of the quantities indicated in part C (i).

- **Label** the vertical and horizontal axes with numerical scales.
- **Plot** the corresponding data points on the grid.
- Table 2 is provided in your booklet for scratch work, but the table will not be scored.

Quantity (units, if appropriate)



Quantity (units, if appropriate)

iii. **Draw** a best-fit line for the data graphed in part C (ii).

Part D

Calculate m from the best-fit line drawn on the grid.

Begin your response to **QUESTION 4** on this page.

4. (10 points, suggested time 20 minutes)

Two particles, 1 and 2, have different mass and charge as described by the following.

- Particle 1 has mass M and negative charge $-Q$.
- Particle 2 has mass $\frac{M}{2}$ and positive charge $+2Q$.

In separate trials, a device is used to accelerate each particle in the $-y$-direction from rest through a potential difference of absolute value $|\Delta V|$. The polarity of the potential difference can be adjusted so that a particle with either positive charge or negative charge can be accelerated in the $-y$-direction by the device. Gravitational effects are negligible.

After moving through the potential difference, particles 1 and 2 exit the device with kinetic energies K_1 and K_2, respectively.

(a) **Calculate** the ratio $\frac{K_2}{K_1}$.

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Continue your response to **QUESTION 4** on this page.

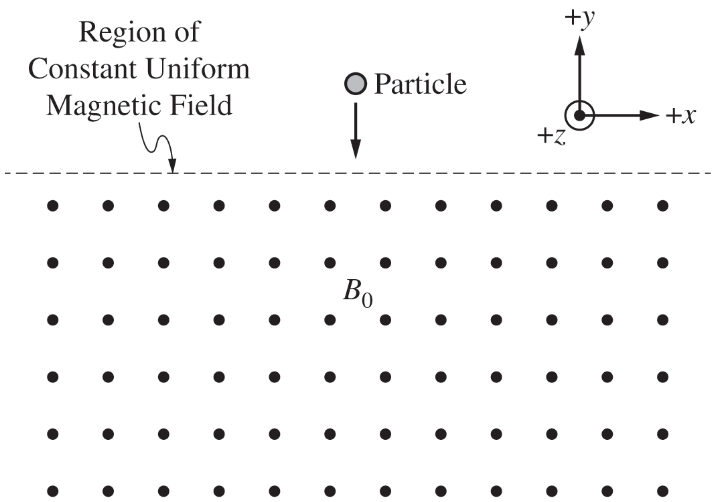

Figure 1

After exiting the device, the particles enter a large region of constant uniform magnetic field of magnitude B_0 that is directed in the $+z$-direction (out of the page), as shown in Figure 1. Each particle is moving in the $-y$-direction when entering the region, and each particle is moving in the $+y$-direction when exiting the region.

(b)

i. **Determine** an expression for the speed of Particle 2 in the region. Express your answer in terms of M, K_2, and physical constants, as appropriate.

ii. **Derive** an expression for the horizontal distance Δx between the locations where Particle 2 enters and leaves the region. Express your answer in terms of M, Q, K_2, B_0, and physical constants, as appropriate.

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Continue your response to **QUESTION 4** on this page.

(c) On the following diagram in Figure 2, **sketch** and clearly **label** the paths of both particles 1 and 2 in the region.

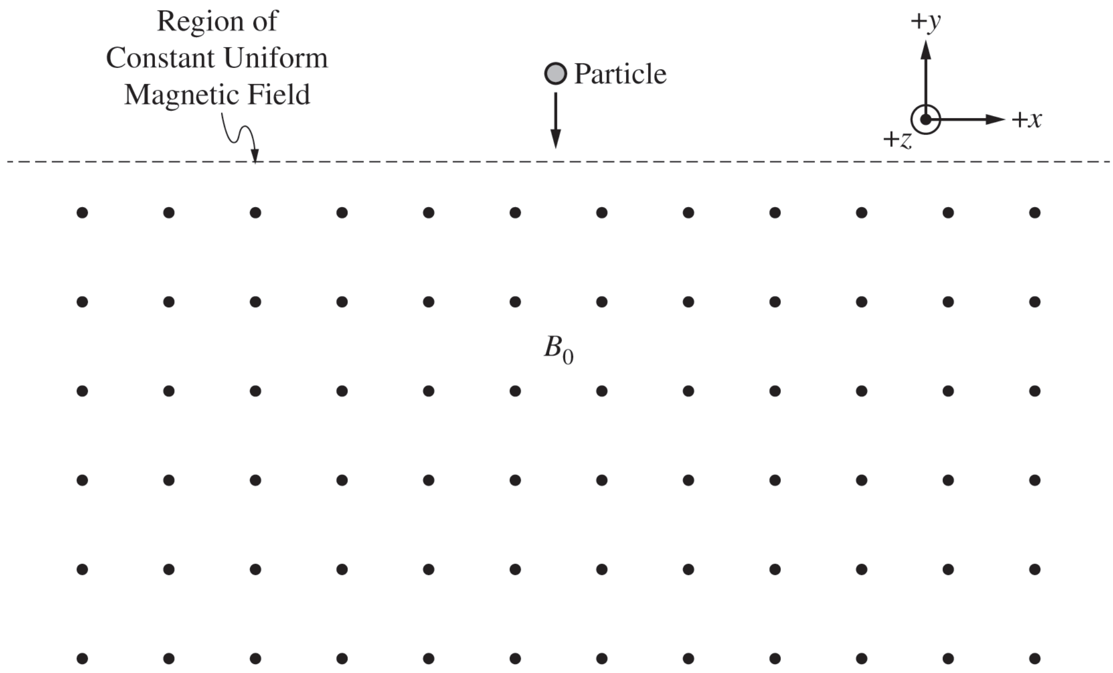

Figure 2

(d) A uniform electric field is added to the region such that Particle 1 of negative charge $-Q$ travels with constant speed in a straight line through the region. **Determine** the direction of the electric field.

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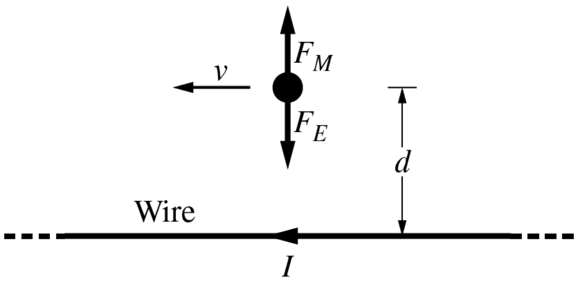
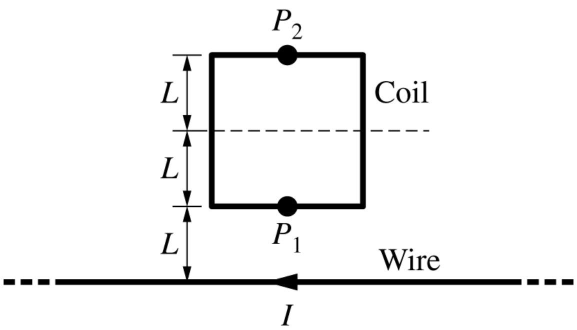
END OF EXAM



. (10 points, suggested time 20 minutes)

At the instant shown above, a negatively charged object is moving to the left with constant velocity v near a long, straight wire that has a current I directed to the left. The region contains a uniform electric field of magnitude E, and the charged object is at a distance d from the wire. The figure shows the electric and magnetic forces, F_E and F_M, respectively, exerted on the charged object.

(a) Derive an expression for v in terms of E, d, I, and physical constants, as appropriate.



(b) The charged object is removed, and a square coil with side length $2L$ is placed near the long, straight wire, as shown above. The bottom of the coil is a distance L from the wire. The magnitude of the magnetic field due to the current in the wire is $3B_0$ at point P_1 and B_0 at point P_2.

i. Write an "X" at a location on the figure where the magnitude of the magnetic field is $2B_0$. Briefly justify your reasoning.

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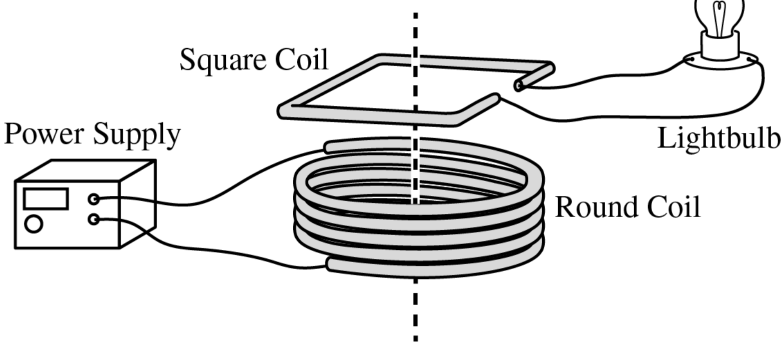
Continue your response to **QUESTION 4** on this page.

ii. Over a time interval of 2.0 s, the current in the wire is decreased. The initial magnetic flux through the coil is $5.0 \times 10^{-5}\ \text{T}\cdot\text{m}^2$ and the final magnetic flux through the coil is $1.0 \times 10^{-5}\ \text{T}\cdot\text{m}^2$. The coil has a total resistance of $10\ \Omega$. Calculate the magnitude of the average current in the coil during the 2.0 s time interval.



The wire is removed and the square coil is positioned so that the coil is directly above and concentric with a round coil of wire connected to a power supply. A part of the square coil is removed and a lightbulb is connected to the coil, as shown above.

(c) During a short time interval, the current in the power supply is constantly increasing. Use physics principles to explain why the lightbulb is lit during the entire time interval.

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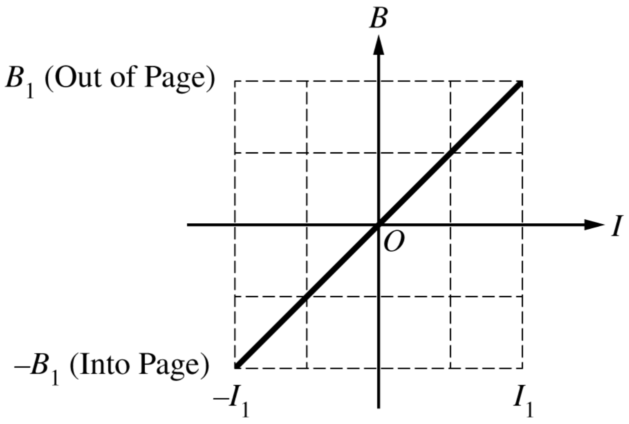
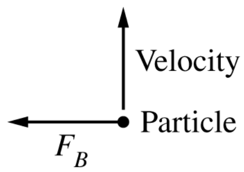
END OF EXAM



Graph 1

3. (12 points, suggested time 25 minutes)

An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.



(a) The current in the electromagnet is set at $0.5I_1$. When a charged particle in the region moves toward the top of the page, the force exerted on it by the field is F_B toward the left, as shown above. What changes to the current in the electromagnet could make the magnitude of the force exerted on the particle equal to $2F_B$ and the direction of the force to the right? Support your answer using physics principles.

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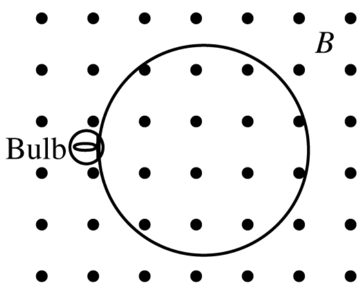
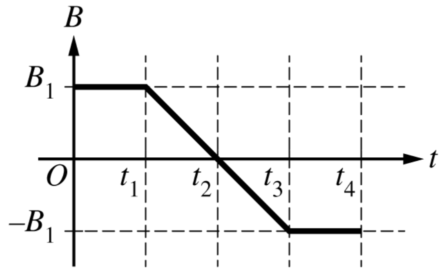
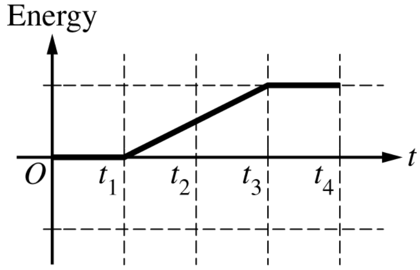




Graph 2

A circuit is made by connecting an ohmic lightbulb of resistance R and a circular loop of area A made of a wire with negligible resistance. The circuit is placed with the plane of the loop perpendicular to the field of the electromagnet, as shown above on the left. The magnetic field changes as a function of time, as shown in Graph 2. The bulb dissipates energy during the interval $t_1 < t < t_3$. Graph 3 below shows the cumulative energy dissipated by the bulb (the total energy dissipated since $t = 0$) as a function of time.



Graph 3

(b) The original bulb is replaced by a new ohmic lightbulb with a greater resistance, but everything else stays the same. How would the cumulative energy graph for the new bulb be different, if at all, from Graph 3 above? Support your answer using physics principles.

GO ON TO THE NEXT PAGE.

(c) The new lightbulb is removed and replaced by the original lightbulb. The magnetic field now changes from $2B_1$ to $-2B_1$ during the same interval $t_1 < t < t_3$. A new cumulative energy graph is created for this situation. How would the new graph be different, if at all, from Graph 3 ? Support your answer using physics principles.

(d) A student derives the following expression for the cumulative energy dissipated by the original bulb during the interval $t_1 < t < t_3$ and with the original change in magnetic field shown in Graph 2.

$$\text{Energy} = \frac{A^2 B_1 R}{4(t_3 - t_1)}$$

Whether or not the equation is correct, does the functional dependence of cumulative energy on the elapsed time $(t_3 - t_1)$ make physical sense? Support your answer using physics principles.

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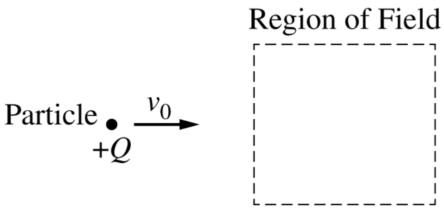
PHYSICS 2

Section II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

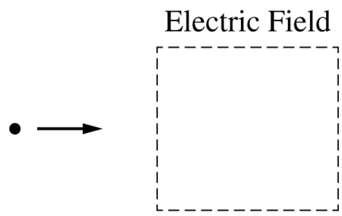


1. (10 points, suggested time 20 minutes)

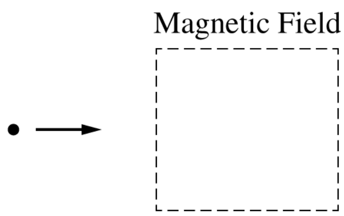
The figure above shows a particle with positive charge $+Q$ traveling with a constant speed v_0 to the right and in the plane of the page. The particle is approaching a region, shown by the dashed box, that contains a constant uniform field. The effects of gravity are negligible.

(a)

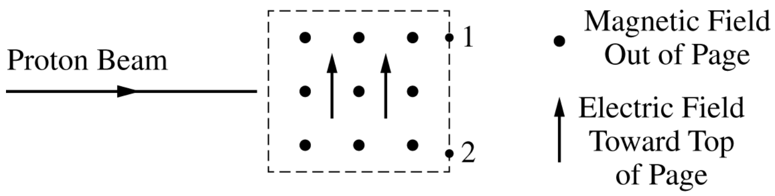
i. On the figure below, draw a possible path of the particle in the region if the region contains only an electric field directed toward the bottom of the page.



ii. On the figure below, draw a possible path of the particle in the region if the region contains only a magnetic field directed out of the page.



iii. For which of the previous situations is the motion more similar to that of a projectile in only a gravitational field near Earth's surface, and why?



(b) Another region of space contains an electric field directed toward the top of the page and a magnetic field directed out of the page. Both fields are constant and uniform. A horizontal beam of protons with a variety of speeds enters the region, as shown above. Protons exit the region at a variety of locations, including points 1 and 2 shown on the figure. In a coherent, paragraph-length response, explain why some protons exit the region at point 1 and others exit at point 2. Use physics principles to explain your reasoning.

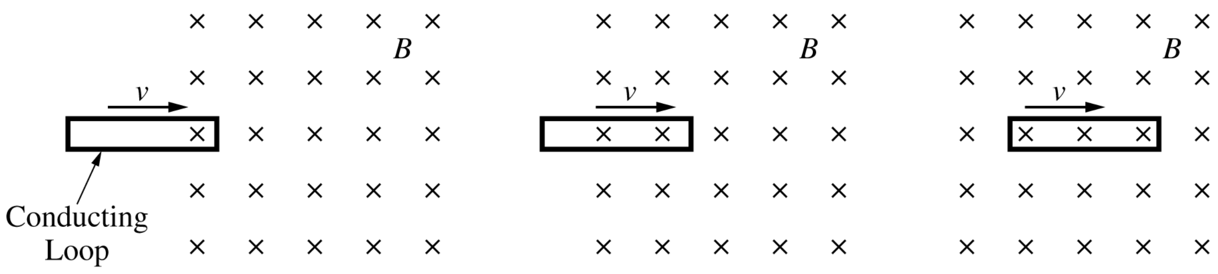
PHYSICS 2

Section II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



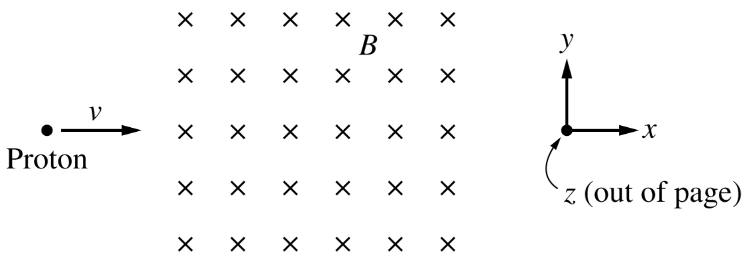
Time t_1 Time t_2 Time t_3

1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

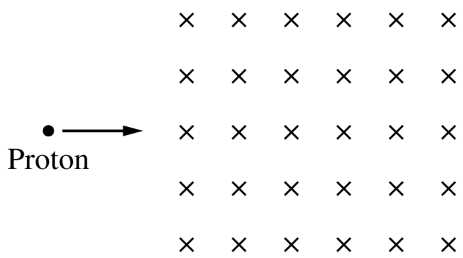
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



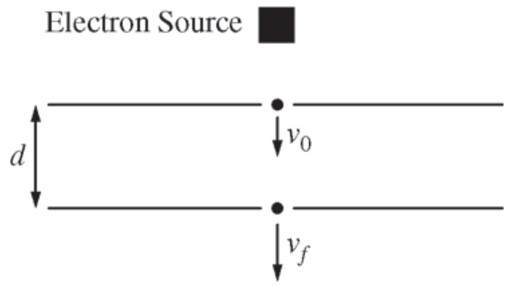
i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).



Note: Figure not drawn to scale.

4. (10 points - suggested time 20 minutes)

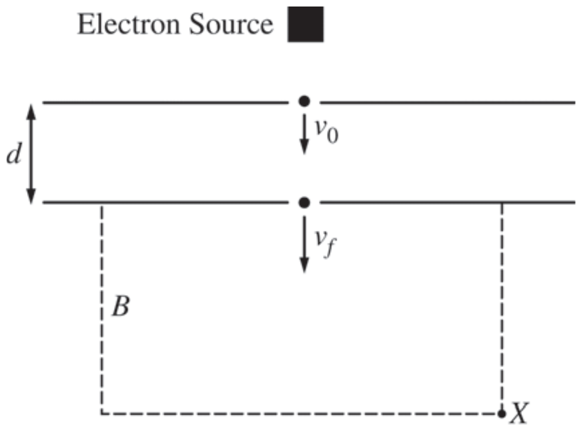
The apparatus shown in the figure above consists of two oppositely charged parallel conducting plates, each with area $A = 0.25\ \text{m}^2$, separated by a distance $d = 0.010\ \text{m}$. Each plate has a hole at its center through which electrons can pass. High velocity electrons produced by an electron source enter the top plate with speed $v_0 = 5.40 \times 10^6\ \text{m/s}$, take $1.49\ \text{ns}$ to travel between the plates, and leave the bottom plate with speed $v_f = 8.02 \times 10^6\ \text{m/s}$.

(a) Which of the plates, top or bottom, is negatively charged? Support your answer with a reference to the direction of the electric field between the plates.

(b) Calculate the magnitude of the electric field between the plates.

(c) Calculate the magnitude of the charge on each plate.

(d) The electrons leave the bottom plate and enter the region inside the dashed box shown below, which contains a uniform magnetic field of magnitude B that is perpendicular to the page. The electrons then leave the magnetic field at point X.



Note: Figure not drawn to scale.

i. On the figure above, sketch the path of the electrons from the bottom plate to point X. Explain why the path has the shape that you sketched.

ii. Indicate whether the magnetic field is directed into the page or out of the page. Briefly explain your choice.

STOP

END OF EXAM

AP PHYSICS 2 • EXERCISE SHEET

12.3 Magnetism and Current-Carrying Wires

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS current-carrying wire 载流导线 • magnetic field 磁场

Objective

Build the skills to answer exam questions on **magnetism and current-carrying wires**.

You must be able to:

- describe the field around a long straight **current-carrying wire 载流导线**, $B = \dfrac{\mu_0 I}{2\pi r}$
- calculate the force on a current-carrying wire in a field, $F = BI\ell \sin\theta$
- explain the attraction or repulsion between two parallel wires

1 Worked examples

Study these first. Each one shows the method for a question type used later.

Field around a wire

$B = \dfrac{\mu_0 I}{2\pi r}$, with $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}; the field circles the wire and weakens with distance.

Force on a wire

$F = BI\ell \sin\theta$ — maximum when the wire is perpendicular to the field.

Parallel wires

Currents in the **same** direction **attract**; in **opposite** directions they **repel**.

2 Practice

2.1 A wire of length 0.20 m carries 3.0 A perpendicular to a 0.50 T field. Find the force. [2]

2.2 State what happens to two parallel wires carrying current in the same direction. [1]

2.3 Find the magnetic field 0.10 m from a long wire carrying 5.0 A ($\mu_0 = 4\pi \times 10^{-7}$). [2]

3 Exam-style questions

3.1 The force on a current-carrying wire in a magnetic field is [1]

- **A** qvB
- **B** $BI\ell$
- **C** $\dfrac{\mu_0 I}{2\pi r}$
- **D** V/R

3.2 Two parallel wires carrying current in **opposite** directions [1]

- **A** attract
- **B** repel
- **C** do nothing
- **D** always melt

3.3 A 0.50 m wire carries 4.0 A at 90° to a 0.25 T field.

(a) Find the force on the wire. [2]

(b) State what happens to the force if the current is doubled. [1]

Solutions

2.1 $F = BI\ell = 0.50 \times 3.0 \times 0.20 = 0.30$ N.

2.2 they attract each other.

2.3 $B = \dfrac{\mu_0 I}{2\pi r} = \dfrac{(4\pi \times 10^{-7})(5.0)}{2\pi(0.10)} = 1.0 \times 10^{-5}$ T.

3.1 **B**.

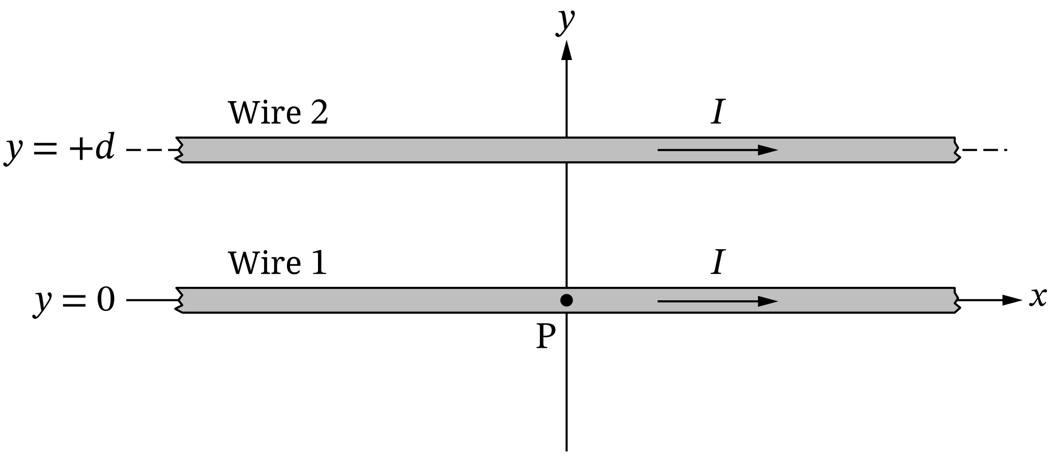
3.2 **B**.

3.3 (a) $F = BI\ell = 0.25 \times 4.0 \times 0.50 = 0.50$ N. (b) it doubles to 1.0 N ($F \propto I$).

Question 1: Version J

1. Very long Wire 1 carries current I in the $+x$-direction along the line $y = 0$. Very long Wire 2 carries current I in the $+x$-direction along the line $y = +d$. Point P is located along Wire 1 at the origin, as shown in Figure 1. The diameters of the wires are small compared to the distance between the wires. Both wires are in the xy-plane.

Figure 1



Note: Figure not drawn to scale.

A.

i. Complete the following tasks in figures 2 and 3. Use either arrows or the symbols shown in the box above the figures for your response.

- **Indicate** the direction of the magnetic field from Wire 2 at Point P in Figure 2.
- **Indicate** the direction of the magnetic force that is exerted on Wire 1 by Wire 2 in Figure 3.

Symbols

✕ Into the page ● Out of the page

Magnetic Field from Wire 2 at Point P

Figure 2

Magnetic Force on Wire 1 by Wire 2

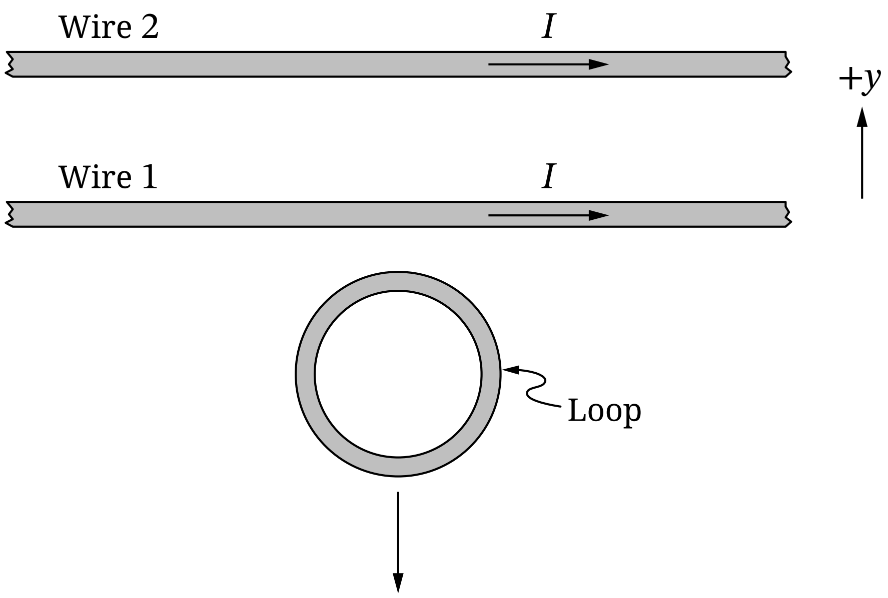
Figure 3

ii. Very long Wire 3 carrying current $2I$ in the $+x$-direction is placed in the xy-plane along the line $y = y_3$. The net magnetic force exerted on Wire 1 by the currents in wires 2 and 3 is zero.

Derive an expression for y_3 in terms of d. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

B. Wire 3 is moved very far away from wires 1 and 2. A circular conducting loop in the *xy*-plane is initially held at rest below Wire 1. The loop is then moved at a constant speed in the $-y$-direction, as shown in Figure 4.

Figure 4



Note: Figure not drawn to scale.

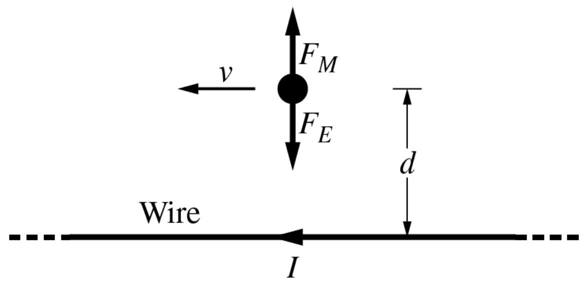
Indicate whether there is a clockwise induced current in the loop, a counterclockwise induced current in the loop, or no induced current in the loop.

______ Clockwise

______ Counterclockwise

______ There is no induced current in the loop.

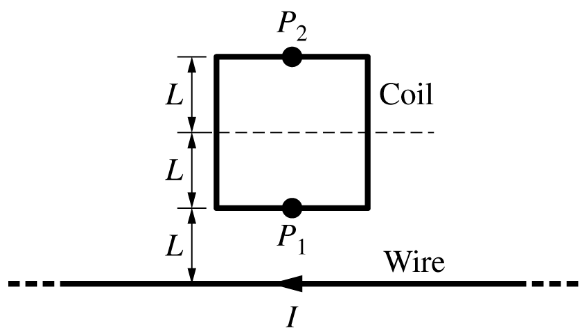
Justify your answer.



. (10 points, suggested time 20 minutes)

At the instant shown above, a negatively charged object is moving to the left with constant velocity v near a long, straight wire that has a current I directed to the left. The region contains a uniform electric field of magnitude E, and the charged object is at a distance d from the wire. The figure shows the electric and magnetic forces, F_E and F_M, respectively, exerted on the charged object.

(a) Derive an expression for v in terms of E, d, I, and physical constants, as appropriate.



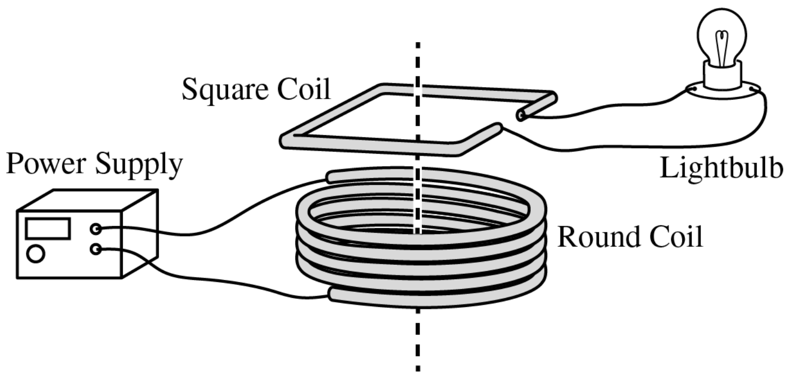
(b) The charged object is removed, and a square coil with side length $2L$ is placed near the long, straight wire, as shown above. The bottom of the coil is a distance L from the wire. The magnitude of the magnetic field due to the current in the wire is $3B_0$ at point P_1 and B_0 at point P_2.

i. Write an "X" at a location on the figure where the magnitude of the magnetic field is $2B_0$. Briefly justify your reasoning.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 4** on this page.

ii. Over a time interval of 2.0 s, the current in the wire is decreased. The initial magnetic flux through the coil is 5.0×10^{-5} T·m^2 and the final magnetic flux through the coil is 1.0×10^{-5} T·m^2. The coil has a total resistance of 10 Ω. Calculate the magnitude of the average current in the coil during the 2.0 s time interval.



The wire is removed and the square coil is positioned so that the coil is directly above and concentric with a round coil of wire connected to a power supply. A part of the square coil is removed and a lightbulb is connected to the coil, as shown above.

(c) During a short time interval, the current in the power supply is constantly increasing. Use physics principles to explain why the lightbulb is lit during the entire time interval.

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

12.4 Electromagnetic Induction and Faraday's Law

Name: ____________ Class: ________ Date: __________ **Total: 10 marks**

KEY WORDS magnetic flux 磁通量 • faraday's law 法拉第定律 • lenz's law 楞次定律 • electromagnetic induction 电磁感应

Objective

Build the skills to answer exam questions on **electromagnetic induction and Faraday's law**.

You must be able to:

- define **magnetic flux 磁通量** as $\Phi = BA\cos\theta$
- state **Faraday's law 法拉第定律**: a changing flux induces an emf, $\varepsilon = -\dfrac{\Delta\Phi}{\Delta t}$
- use **Lenz's law 楞次定律** to find the direction of an induced current
- describe how generators and transformers use induction

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ Magnetic flux

$\Phi = BA\cos\theta$, measured in webers, where θ is the angle between the field and the loop's normal. Flux is greatest when the loop faces the field ($\theta = 0$).

■ Faraday's law

$\varepsilon = -\dfrac{\Delta\Phi}{\Delta t}$: a **changing** flux induces an emf. A faster change means a larger emf.

■ Lenz's law

The induced current flows so as to **oppose** the change in flux that produced it (the minus sign).

2 Practice

2.1 Find the magnetic flux through a 0.20 m^2 loop lying face-on in a 0.50 T field. [2]

2.2 State what is needed to induce an emf in a coil. [1]

2.3 State Lenz's law. [1]

3 Exam-style questions

3.1 Magnetic flux is [1]

- **A** $BA\cos\theta$
- **B** $BI\ell$
- **C** qvB
- **D** $\dfrac{\mu_0 I}{2\pi r}$

3.2 The rule that an induced current opposes the change that causes it is [1]

- **A** Ohm's law
- **B** Faraday's law
- **C** Lenz's law
- **D** Kirchhoff's law

3.3 The flux through a coil falls from 0.40 Wb to 0.10 Wb in 0.20 s.

(a) Find the size of the induced emf. [3]

(b) Name the law used. [1]

Solutions

2.1 $\Phi = BA\cos 0° = 0.50 \times 0.20 = 0.10$ Wb.

2.2 a changing magnetic flux through the coil.

2.3 the induced current opposes the change in flux that produces it.

3.1 **A**.

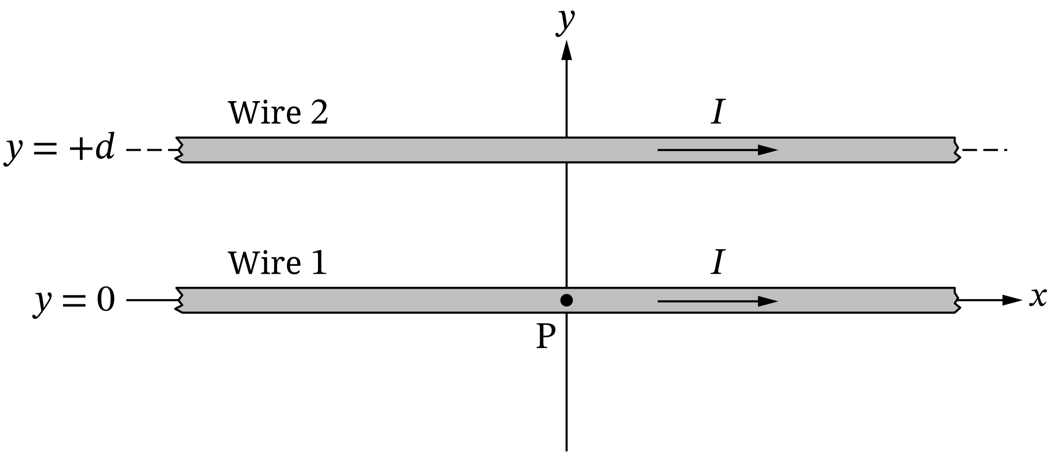
3.2 **C**.

3.3 (a) $|\varepsilon| = \left|\frac{\Delta\Phi}{\Delta t}\right| = \frac{0.40 - 0.10}{0.20} = 1.5$ V. (b) Faraday's law.

Question 1: Version J

1. Very long Wire 1 carries current I in the $+x$-direction along the line $y = 0$. Very long Wire 2 carries current I in the $+x$-direction along the line $y = +d$. Point P is located along Wire 1 at the origin, as shown in Figure 1. The diameters of the wires are small compared to the distance between the wires. Both wires are in the xy-plane.

Figure 1



Note: Figure not drawn to scale.

A.

i. Complete the following tasks in figures 2 and 3. Use either arrows or the symbols shown in the box above the figures for your response.

- **Indicate** the direction of the magnetic field from Wire 2 at Point P in Figure 2.
- **Indicate** the direction of the magnetic force that is exerted on Wire 1 by Wire 2 in Figure 3.

Symbols

× Into the page ● Out of the page

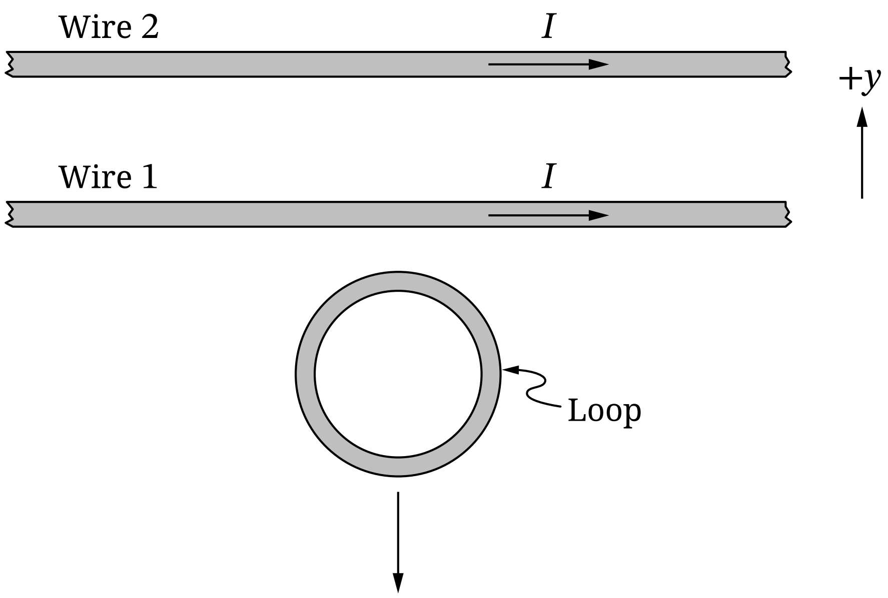
Magnetic Field from Wire 2 at Point P	Magnetic Force on Wire 1 by Wire 2
Figure 2	Figure 3

ii. Very long Wire 3 carrying current $2I$ in the $+x$-direction is placed in the xy-plane along the line $y = y_3$. The net magnetic force exerted on Wire 1 by the currents in wires 2 and 3 is zero.

Derive an expression for y_3 in terms of d. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

B. Wire 3 is moved very far away from wires 1 and 2. A circular conducting loop in the xy-plane is initially held at rest below Wire 1. The loop is then moved at a constant speed in the $-y$-direction, as shown in Figure 4.

Figure 4



Note: Figure not drawn to scale.

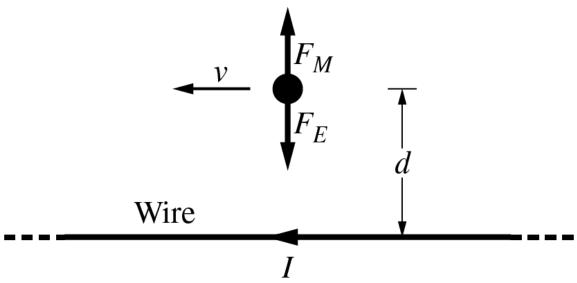
Indicate whether there is a clockwise induced current in the loop, a counterclockwise induced current in the loop, or no induced current in the loop.

______ Clockwise

______ Counterclockwise

______ There is no induced current in the loop.

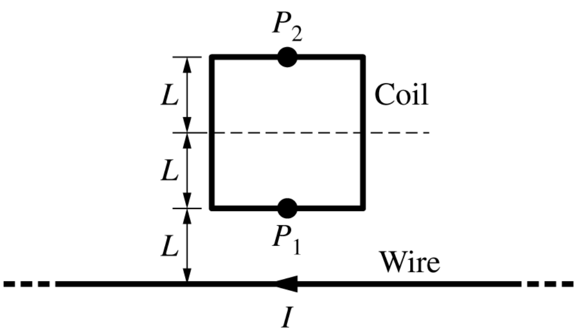
Justify your answer.



. (10 points, suggested time 20 minutes)

At the instant shown above, a negatively charged object is moving to the left with constant velocity v near a long, straight wire that has a current I directed to the left. The region contains a uniform electric field of magnitude E, and the charged object is at a distance d from the wire. The figure shows the electric and magnetic forces, F_E and F_M, respectively, exerted on the charged object.

(a) Derive an expression for v in terms of E, d, I, and physical constants, as appropriate.



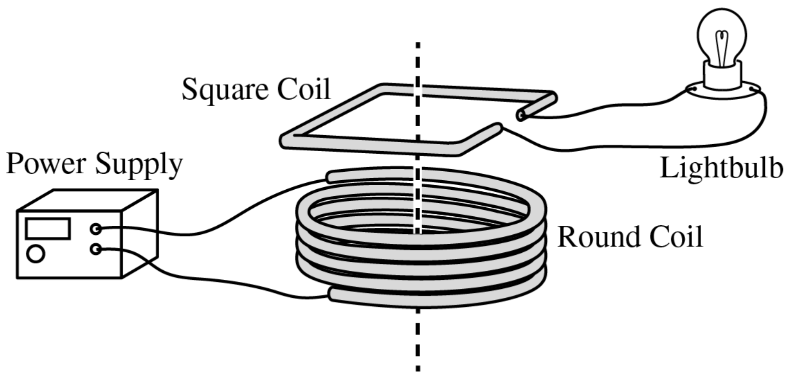
(b) The charged object is removed, and a square coil with side length $2L$ is placed near the long, straight wire, as shown above. The bottom of the coil is a distance L from the wire. The magnitude of the magnetic field due to the current in the wire is $3B_0$ at point P_1 and B_0 at point P_2.

i. Write an "X" at a location on the figure where the magnitude of the magnetic field is $2B_0$. Briefly justify your reasoning.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 4** on this page.

ii. Over a time interval of 2.0 s, the current in the wire is decreased. The initial magnetic flux through the coil is $5.0 \times 10^{-5}\ \text{T}{\cdot}\text{m}^2$ and the final magnetic flux through the coil is $1.0 \times 10^{-5}\ \text{T}{\cdot}\text{m}^2$. The coil has a total resistance of 10 Ω. Calculate the magnitude of the average current in the coil during the 2.0 s time interval.



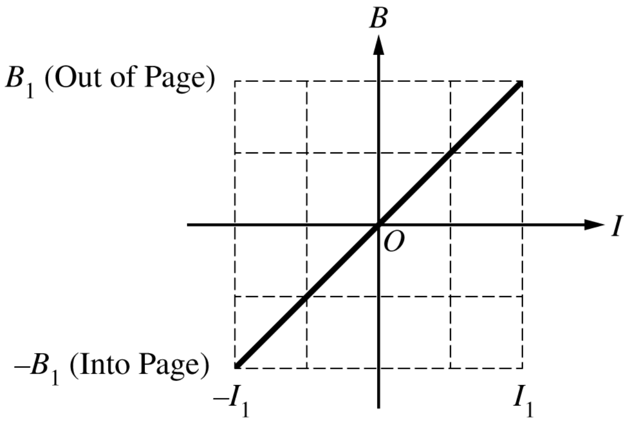
The wire is removed and the square coil is positioned so that the coil is directly above and concentric with a round coil of wire connected to a power supply. A part of the square coil is removed and a lightbulb is connected to the coil, as shown above.

(c) During a short time interval, the current in the power supply is constantly increasing. Use physics principles to explain why the lightbulb is lit during the entire time interval.

GO ON TO THE NEXT PAGE.

STOP

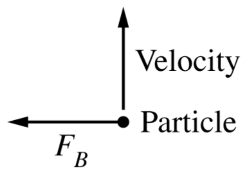
END OF EXAM



Graph 1

3. (12 points, suggested time 25 minutes)

An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.



(a) The current in the electromagnet is set at $0.5I_1$. When a charged particle in the region moves toward the top of the page, the force exerted on it by the field is F_B toward the left, as shown above. What changes to the current in the electromagnet could make the magnitude of the force exerted on the particle equal to $2F_B$ and the direction of the force to the right? Support your answer using physics principles.

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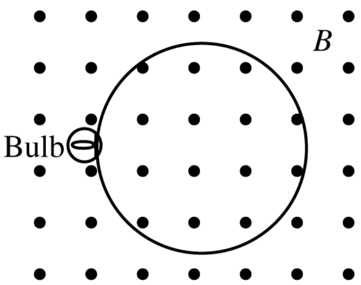
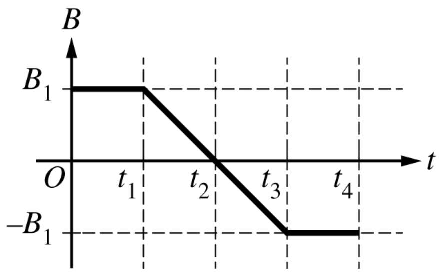
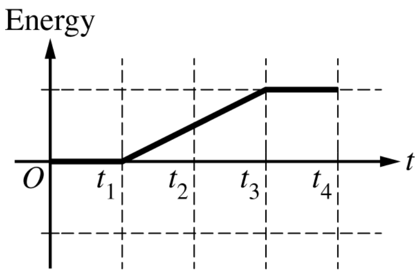




Graph 2

A circuit is made by connecting an ohmic lightbulb of resistance R and a circular loop of area A made of a wire with negligible resistance. The circuit is placed with the plane of the loop perpendicular to the field of the electromagnet, as shown above on the left. The magnetic field changes as a function of time, as shown in Graph 2. The bulb dissipates energy during the interval $t_1 < t < t_3$. Graph 3 below shows the cumulative energy dissipated by the bulb (the total energy dissipated since $t = 0$) as a function of time.



Graph 3

(b) The original bulb is replaced by a new ohmic lightbulb with a greater resistance, but everything else stays the same. How would the cumulative energy graph for the new bulb be different, if at all, from Graph 3 above? Support your answer using physics principles.

GO ON TO THE NEXT PAGE.

(c) The new lightbulb is removed and replaced by the original lightbulb. The magnetic field now changes from $2B_1$ to $-2B_1$ during the same interval $t_1 < t < t_3$. A new cumulative energy graph is created for this situation. How would the new graph be different, if at all, from Graph 3 ? Support your answer using physics principles.

(d) A student derives the following expression for the cumulative energy dissipated by the original bulb during the interval $t_1 < t < t_3$ and with the original change in magnetic field shown in Graph 2.

$$\text{Energy} = \frac{A^2 B_1 R}{4(t_3 - t_1)}$$

Whether or not the equation is correct, does the functional dependence of cumulative energy on the elapsed time $(t_3 - t_1)$ make physical sense? Support your answer using physics principles.

GO ON TO THE NEXT PAGE.

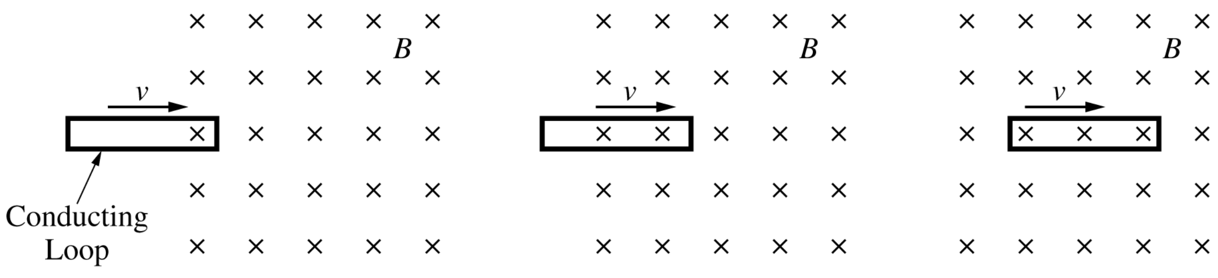
PHYSICS 2

Section II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



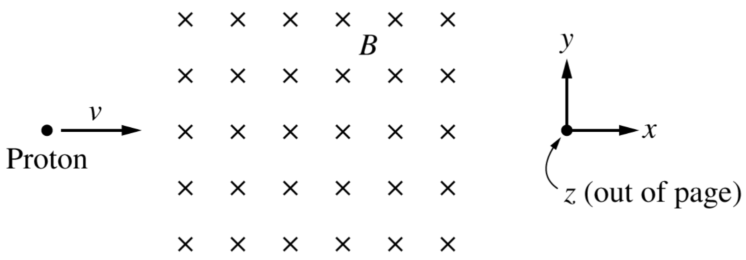
Time t_1 Time t_2 Time t_3

1. (10 points, suggested time 20 minutes)

   The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

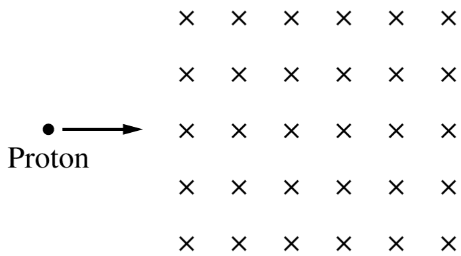
   (a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).